DYNAMIC RESPONSE OF A GROUP OF SYNCHRONOUS GENERATORS FOLLOWING DISTURBANCES IN DISTRIBUTION GRID

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Abstract:

The connection of distributed sources and their impact on distribution grid has been the subject of intensive research in the last two decades. Creating a favorable environment for the production of electrical energy from renewable energy sources in many countries around the world made an evident increase in electrical energy production from renewable sources. Connecting these generators to distribution grid is not always an easy task, and often, in cases of inadequate analysis and poor choice of ways of connecting these sources, can have a negative impact on the quality of electrical energy in local distribution grids. In this paper, using a realistic test system, the focus of research is to identify the behavior of group synchronous generators connected to the medium-voltage distribution grid in "cascade" manner. The selected test system presents the real power distribution system of the Municipality of Gornji Vakuf-Uskoplje, to which six synchronous generators are connected at the moment. Analyses results of the work of this power distribution system in the previous period indicate that there have been significant changes in the existing distribution grid (significant change in voltage, increased losses, etc.) after these generators were connected. Dynamic simulations are conducted on the basis of the appropriate mathematical models, and the response of the generators and changes in the voltage value in the distribution grid were simulated for several types of disturbances. The results show that generators remain in synchronism while tested on selected simulated disturbances, where the oscillations of the generator rotor disappear over a period of several seconds. Also, the changes of voltage value in distribution grids for simulated disturbances are within the permitted limits.

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1 Introduction

Connecting distributed generators (DG) to distribution grids and assessment of its impact on quality parameters of electrical energy have been the subject of research for many years. Defining requirements for connecting DG to distribution grids is not always an easy task and usually requires detailed analysis. These analyses generally are the standard static analysis of power flow calculations, voltage conditions and power losses caused by different conditions in the distribution grid, upon which adequate criteria are checked. The connection of a large number of DG to distribution grid attracts considerable attention in the context of different analyses of the complete observed system. As in references [1-3], the authors analyze in detail the impact of DG connection to the power system in the context of stability and system management with a focus on the transmission network. Practical analysis of DG impact on distribution grids can be found in the references [4-6], where the response of generators to different kinds of disturbances in distributive grids is being studied, and in the reference [7] the authors are studying various techniques of signal processing in networks with DG connected grids. In this paper, using the real power distribution system to which six synchronous generators are connected, the response of synchronous generators to certain disturbances is analyzed. This test system attracts special attention since all six generators are connected and operating on a single 20 kV distribution line. Simulation results of different types of disturbances (turning on and off the power line, short circuit, etc.) show that synchronous generators after simulated disturbance maintain synchronism, and subsequent oscillations in the observed test system disappear after a few seconds. Also, the changes in the voltage value in the distribution system during transient process remain within the permitted limits. This paper is organized as follows:

The second part briefly presents methodology and models used. The third chapter presents data on the test system and the simulation results with the appropriate discussion. The fourth chapter is dedicated to conclusions.

2 Background

The analysis of transient stability is very complex and requires solution of differential equations describing dynamic characteristics of the elements of power system. Also, it usually involves observing the response of generator to disturbance and analysis of power-angle curve for which the equal area criterion is commonly used [8, 9]. The equation of rotor motion can be presented by the relation [9]:

$$\frac{2H}{\omega_0} \cdot \frac{d^2\delta}{dt^2} = \overline{M_m} - \overline{M_e} \tag{1}$$

where:

H – inertia constant of the machine (generator and turbine),

$\overline{M_e}$– electric torque (given),

$\overline{M_m}$– achieved mechanical torque and

ω_0– rated angular velocity.

An additional term ($-K_D\Delta\overline{\omega_r}$) may be added to the right side of [Eq. (1)] to account for a component of damping torque not included explicitly in M_e, and $\overline{\omega_r}$ it denotes the angular velocity of the rotor.

Due to broadness and complexity of this issue, a detailed mathematical elaboration will be omitted in this paper. Modeling of test system elements and practical simulations were done in MATLAB-PSAT (Power System Analysis Toolbox) [10]. All six generators of the test system are presented by the IV level model [10]. Automatic voltage regulator (AVR) of all generators are presented by type 2 in the available library of used software which corresponds to the model AVR IEEE type 4 [10]. Besides, turbine regulators (TR) are represented with the corresponding models of type II in the available library of used software. For all details related to the equivalent diagrams and mathematical equations describing the above elements, the reader is referred to Ref. [10].

3 Test system - real power distribution system

Six small hydropower plants with total installed capacity of 6828 kW are connected to the distribution test system. SHHP are connected to TS 110/20/10 kV Gornji Vakuf-Uskoplje with 20 kV line. The load of this distribution system ranges from a minimum of 1 MW to a maximum of 7,8MW. As the total installed capacity of the connected SHHP for this test system is relatively large, there are cases, in practical functioning of the power plant at maximum production, when production from SHPP is significantly higher than local consumption. In this case, the surplus of electrical energy produced by SHPP is distributed to the transmission grid. Significantly, higher losses in the distribution grid are identified in such working conditions [11]. The total number of consumers in the observed distribution area is approximately 4400, and total number of TS 10(20)/0.4kV which supply consumers is 108. Single line diagram of the test system is shown in Fig. 1, while the installed capacity of the SHHP is shown in Tab. 1.

Table 1. SHPP installed capacity

SHPP	Rated Voltage (kV)	Installed capacity (kW)
SHPP1	0.4	872
SHPP2	0.4	612
SHPP3	0.4	340
SHPP4	0.4	1277
SHPP5	0.4	812
SHPP6	10	2915

Technical data on the analyzed grid, except for information on generators, were taken from the technical database of the state electrical utility company JP *Elektroprivreda BiH* dd Sarajevo. Since all available measurements (peak power of industrial loads, measurements at 10(20) /0.4 kV, etc.) were not available to the authors of this paper, the load on TS 20(10)/0.4 kV are estimated on the basis of the installed power transformers and the total peak load of the observed consumer areas. Lines, transformers, load balancing node (on 110kV side of TS 110/20/10 kV) are modeled on the basis of [3, 8, 10]. The following are basic information about the model:

NETWORK STATISTICS:

Buses:	285
Lines:	169
Transformers:	117
Generators:	7
Loads:	107

TOTAL GENERATION:

Real Power [MW]:	7.8595
Reactive Power [MVAr]:	1.9080

TOTAL LOAD:

Real Power [MW]:	7.3745
Reactive Power [MVAr]:	2.4336

Also, detailed information on generators, AVR and TR were not available to the authors, so they were taken from [4]. Of course, it should be noted that different data on generators would result in different responses to simulated disturbances. Tables 2-5 show the input data used in the simulations and practical analyses.

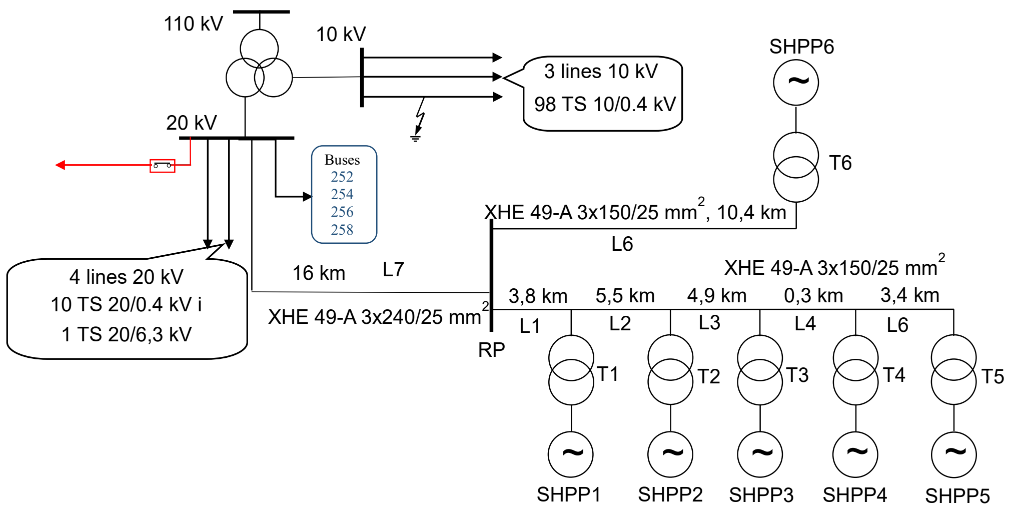

Figure 1. Diagram of distribution test system.

Table 2. Transformers data

	(MW)	kV/kV	R (p.u.)	L (p.u.)
T1 _2 _5	1	20/0.4	0.0135	0.05846
T3	0.4	20/0.4	0.0115	0.038311
T4	1.6	20/0.4	0.012375	0.058709
T6	3.5	20/10	6.88e-3	0.057187

Table 3. Line data

Line	R(Ω/km)	L(H/km)	C (F/km)
L1-L6	0.206	0.00036	0.254e-6
L7	0.125	3.184e-4	0.125e-6

Table 4. Generator models data (SHPP 1 - 6) (p.u).

r_a	0.004
x_l	0.1
x_d	1.8
x'_d	0.166
x''_d	0.119
T'_{d0}	1.754
T''_{d0}	0.19
x_q	1.793
x'_q	0.98
x''_q	0.17
T'_{q0}	0.05
T''_{q0}	0.164
H	2

Table 5. AVR data (SHPP 1 - 6)

Maximum Regulator Voltage (p.u.)	3.5
Minimum Regulator Voltage (p.u.)	0
K_a (p.u.)	10
T_a (s)	0.03
K_f (p.u.)	0.5
T_f (s)	1.0
K_e (s)	0.01
T_d (s)	1.0
T_r (s)	0.001

Table 6. TR data (SHPP 1 - 6)

Reference speed (p.u.)	1.0
Droop R (p.u.)	10
Maximum torque (p.u.)	0.9
Minimum torque (p.u.)	0
Pole Time Constant T2 (s)	0.10
Zero Time Constant T1 (s)	0.65

3.1 Simulation of selected disturbances

This paper analyzes several disturbances that are common to the distribution grid, and the simulation results are shown only for the following selected cases.

Case I: gives a simulation of a three phase fault analysis in 10 kV grid where disturbance occurs at the time t = 0.1 s and lasts t = 0.15 s.

Case II: gives a simulation of activation of one 20 kV line with total load of 1 MW, also in t = 0.1 s.
Results of the response of synchronous generators to selected disturbances in power distribution grid and change in load voltage are presented in Fig. 2-5, with the corresponding explanation.
For the first simulated case (TFSC in 10 kV grid), oscillations in angular velocity of all six connected generators are shown in Fig. 2.

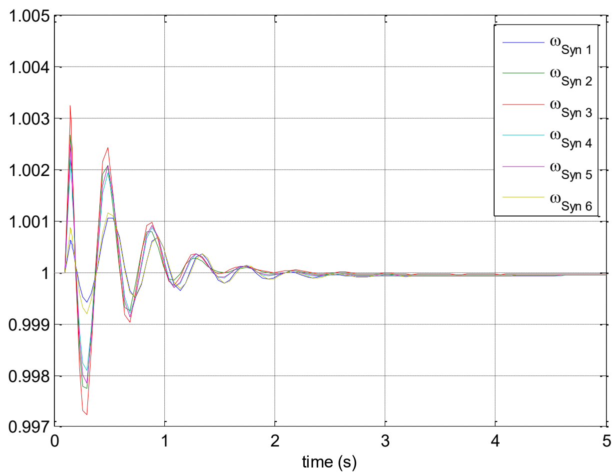

Figure 2. Case I_ Angular velocity.

Immediately after the simulated failure, distributed generators accelerate and the maximum value of angular velocity achieved by SHPP3 is ω=157,502 rad/s (1.0032 p.u). The minimum value of angular velocity also achieved by SHPP3 3 is ω= 156,607 rad/s (0.9975 p.u.), which is a generator with minimum installed capacity in the observed system. Furthermore, the voltage change on several selected buses at the consumers' side in case of simulated disturbance is shown in Fig. 3, where V_{252}, V_{254}, V_{256} and V_{258} are voltages on the selected buses at the consumers' that are connected to the power distribution grid through a 20 kV output.

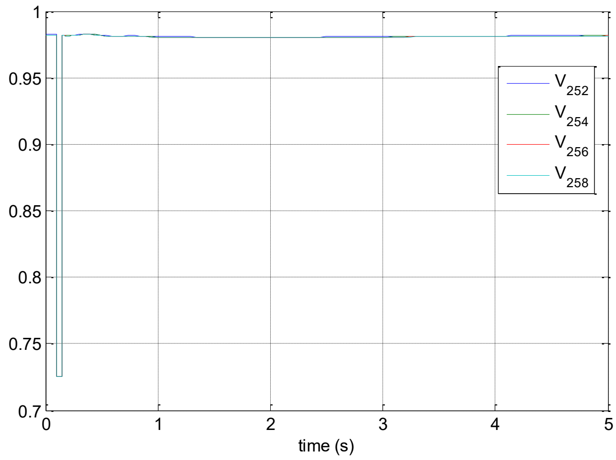

Figure 3. Case I_Change in voltage due to disturbance.

Immediately after TFSC simulation, voltage on the 0,4 kV buses tends to reach zero value, but due to distance from the point of failure, this value has not reached zero value . The minimum voltage value achieved on the bus No. 258 is U= 290 V (0.725 p.u.). In case of this simulated disturbance, SHPP returned to the initial stationary state in just a few seconds after disturbance. In this simulated disturbance, generators maintained synchronism while voltage changes in the grid (after elimination of the failure) were basically negligible.

In the second simulated case (activation of the load at 20 kV buses), oscillations of angular velocity of all six connected generators are shown in Fig. 4. Immediately after the activation of load, the distributed generators are slowing down, and the minimum value of the angular velocity achieved by distributed generator 1 is ω = 156,655 rad /s (0.9978 pu). Furthermore, the voltage change at several selected buses at the final load in this case of simulated disturbance, is shown in Fig. 5, where V_{252}, V_{254}, V_{256} and V_{258} are the voltages at selected load buses that are connected to the power distribution grid through a 20 kV output. Immediately after the simulated activation of additional load, there was a negligible decrease in voltage at the 0,4 kV buses.

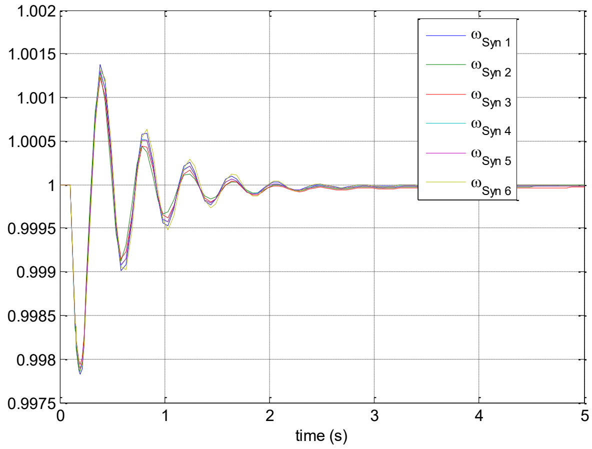

Figure 4. Case II_ Angular velocity.

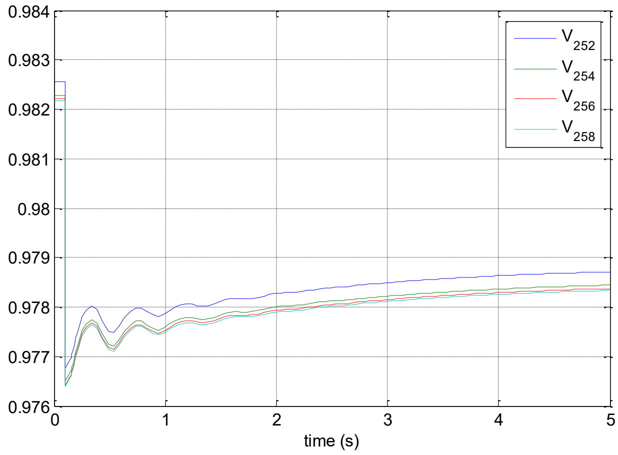

Figure 5. Case II_Change in voltage due to disturbance.

The minimum voltage value identified at the bus is No. 258 U = 390.6 V (0.9765 p.u.). In this case of simulated disturbance, SHHP returned to the initial stationary state in several seconds after disturbance. In this simulated case, which is generally a common type of power distribution management systems, generators maintain synchronism with negligible changes in voltage in the grid during the transient process. Based on the achieved results it can be concluded that the oscillations of a synchronous generator in simulated disturbance last for a relatively short period (several seconds), and voltage values at the 0,4 k V buses do not exceed the maximum and minimum permitted voltage deviation from the nominal value (for LV system it is + 5% and - 10% Un and for MV it is ± 10% Un).

It should be noted that due to RI^2 losses, resistance R contributes to the fact that part of the accumulated kinetic energy is more easily absorbed into the system, thereby contributing to maintaining the transient stability after fault clearance.

Conclusion

This paper presents a study of transient stability of the distribution system with six connected synchronous generator on a single MV line, which is a component part of the real distribution system and a rather specific case. Based on the results, it can be concluded that the synchronous generators are transiently stable at simulated disturbances and oscillations of the rotor angle disappear in a few seconds. Also, consumer load monitoring shows that the voltage values do not exceed the maximum and minimum permitted deviations during the transition process. Of course, it should be noted here that the simulations conducted for voltage values are close to the nominal values. However, in real conditions, at minimum load and maximum production of the observed generators there are conditions in which voltage values can get very high values. Therefore, special attention should be paid to the control of reactive power generation. Also, in these cases of increased voltage, it is necessary to take into account the installed overvoltage protection and the ability to estimate its potential effects. In addition, for some of the selected disturbances, it was not possible to conduct simulations, which is probably a consequence of the complexity and size of models, but also the characteristics of the used software tools. What makes this model or real power distribution system specific, is the possibility of MV grid manipulation and switching some DG to 10 kV lines. According to the static calculations, there are cases where, from the aspect of grid losses (loss reduction), it is worth more if some of the DGs do not produce at full capacity which falls within the scope of optimal power flow and ancillary services in distribution system, which is an area of future research.

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